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Planting Depth and its Influence on Survival and Growth

A Literature Review with Emphasis
on Jack Pine, Black Spruce and White Spruce

by:
Terry Schwan

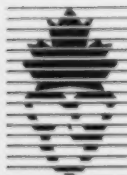
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ABSTRACT

Planting with the root collar level with the soil surface is normal practice in Ontario, but there is evidence that deeper planting can improve performance of outplanted jack pine, black spruce and white spruce. Eleven relevant studies were reviewed from the literature. Factors affecting performance as related to deep planting are moisture, nutrient relations, root deformation, rooting habit, heat stress, frost heaving, and low soil temperature. Information on current practices was obtained through personal communication. Planting jack pine up to 4 cm deeper than the root collar will not be detrimental on typical jack pine sites, and may even promote survival and growth. Black spruce can be planted at least to the level of the first branches in unsaturated mineral soils, without affecting performance,

but survival may be imperilled if planting is deeper than this (foliage buried) in imperfectly drained or wetter mineral soils. In soils susceptible to frost, heaving deep planting (- 4 cm) may increase survival. In sphagnum, planting 2 to 4 cm deep will provide more stability to the seedling which may more than offset the disadvantages of deep planting in a poorly drained soil. Adventitious roots will grow and form the main elements of the root system. For white spruce, more information is needed for conditions in northern Ontario to determine the effect of deep planting. Adventitious roots will develop, but it is not known if this will delay or promote establishment and growth. The recommendation at this time is to plant white spruce with root collar level to mineral soil.

PREFACE

Some of the literature reviewed made no reference to statistically sound principles or mentioned whether they were properly controlled experiments. Where the experiment was set up in a properly controlled design with valid statistical inferences the word "significant" or "significantly" is used to

mean that the probability is five percent or less than the observed variation among means could occur by chance. In some cases, reference is made to the lack of validity in the trials or no reference is made at all. The reader should realize the greater weight of statistically valid evidence.

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1 INTRODUCTION

Current practice in Ontario for planting tree seedlings, whether bareroot or container stock, is to place the root collar level with the soil surface¹ (**Figure 1**). This accords with past practice, reviewed by Sutton (1967); most authorities up to the 1950's considered deep planting to be bad for conifers and particularly bad for spruce (Nisbet 1905; Reuss 1907; Tourney 1916; Hosley 1936). The commonly held view was that seedlings should be planted precisely at the depth they were grown in the nursery (Lyons 1925; Rudolf 1950; Hawley and Smith 1954; Anon 1955). Deep planting is defined as planting the root collar below the surface of the soil. In the case of mineral soil with an organic cover, it usually means placing the root collar below the depth of the mineral soil.

Planting shallow (defined as planting so that the root collar is above the soil surface whether mineral or organic) has proven detrimental and is discouraged (Mullin 1964, 1966; Cleary *et al.* 1978). However, deep planting within reason appears to be a viable option for most species especially to improve survival. (Sutton 1967; Cleary *et al.* 1978). Deep planting of some southern pines has been shown to be advantageous to survival and growth (Slocum and Maki 1956; Switzer 1960).

Among various advantages claimed for deep planting² are:

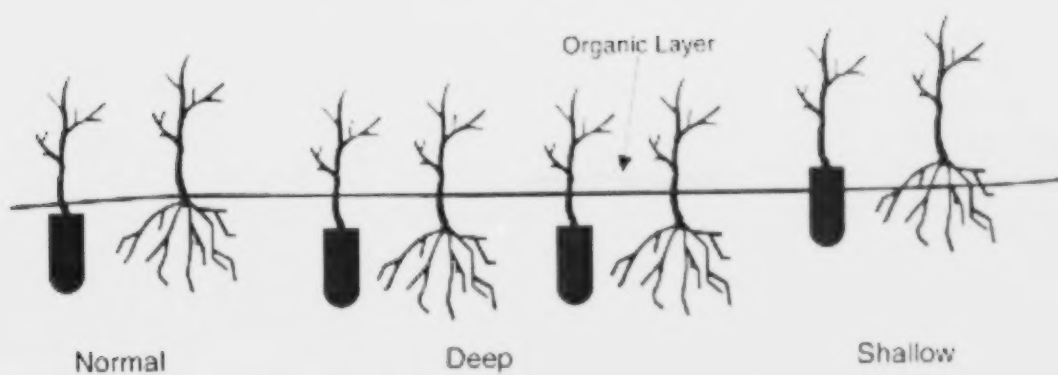
- the planter has more leeway in tree placement in deep soils and as a result may achieve higher productivity.
- the possible reduction of frost heaving.
- a reduced need for scarification if the purpose is to put the roots in contact with the mineral soil.
- reduction of moisture stress on seedlings on dry sites.

This paper reviews the literature on deep planting with particular emphasis on jack pine (*Pinus banksiana* Lamb.), black spruce (*Picea mariana* (Mill.) B. S.P.), and white spruce (*Picea glauca* (Moench) Voss). Literature on deep planting of other North American conifers is also reviewed. Explanations (as described in the literature) of environmental and biological consequence are provided. Current planting practices are described. Finally, the current findings as they apply to the three featured species will be summarized.

¹ from the Ontario tree planting contract Schedule B - Planting Specifications Paragraph 4.4

² paper presented by W. Brown, Corner Brook Pulp and Paper Co. Ltd., Nfld. at the Ontario Silviculture Contractor's Association meeting Feb., 1991.

Figure 1. Definitions of planting at different depths.



2. DEEP PLANTING STUDIES

A total of 11 studies on 25 sites that refer to the featured species were found in the literature or unpublished reports. Fifteen of the studies were with container stock and 11 involved bareroot stock. Jack pine was included in ten trials, black spruce in 11 and white spruce was involved in four.

JACK PINE

A summary of all the jack pine deep planting trials is presented in Table 1. In 1986, a planting demonstration was established on the Shining tree Crown Management Unit near Gogama, Ont. (Maslis 1990). Jack pine bareroot stock (2+0) was planted 1) "properly" at root collar, 2) deep with root collar at 2.5 cm, and 3) 5 cm below mineral soil, 4) shallow at root expansion level, and 5) with roots exposed. Container stock (408 paperpot) was planted 1) "properly" 2) 2.5 cm deep, and 3) shallow with the paperpot visible. The site was a glacio-fluvial outwash plain. The soil profile was a thin, gravelly, fine sandy loam over a medium to coarse sand. Moisture regime was moderately dry with rapid to very rapid drainage. Competition after four years was non-existent.

After one year, bareroot seedlings planted deep had similar survival to the control (98 percent) while seedlings planted shallow and with roots exposed (94 percent and 86 percent survival respectively) had significantly lower survival than the control.³ After six years, differences in survival were not significant (Paterson and Maki 1994). Survival rankings were 5 cm deep (89 percent), control

(86 percent), shallow (84 percent), 2.5 cm deep (84 percent) and roots exposed (76 percent). Immediately after planting, shallow-planted seedlings were significantly taller than those planted deep. Differences in total height were not significant six years later. Rankings for total height, tallest to shortest, were 5 cm deep, control, shallow, 2.5 cm deep, and roots exposed, respectively. All container stock treatments greater than 92 percent survival after six years. After planting, the deep planted stock was significantly shorter than the control or shallow-planted material. After six years there were no significant differences in total height.

Trials were established in the Abitibi region of northwest Quebec in 1984 and 1985 at three different sites described by township, (Bacon 85, Chaste 84, Chaste 85) to test the effect of planting depth on survival, growth and frost heaving (Anctil and Cossette 1989). The soils were well drained clays with 5 to 15 cm of mor humus. The sites were prepared with a TTS scarifier and the seedlings were planted on the side of the furrow. Jack pine in containers and as 2+0 (2 sites) and 3+0 (1 site) bareroot was planted with the root collar at 0, 2, 4, 6, and 8 cm below the mineral soil.

Results of chi-square analysis indicated no strong effect of treatment on survival. After six years, survival on the three sites averaged

³ Unpublished data developed by John Paterson Regeneration Specialist, Ontario Forest Research Institute, Ministry on Natural Resources, Sault Ste. Marie, ON.

Table 1. Summary of deep planting trials for jack pine

Location	Establishment (year)	Stock Type	Soil Texture Drainage	Burial (cm)	Growth (years)	Survival (%)	Height (cm)	Source and Experimental Design
Sault Ste. Marie	1977	408 paperpot; O/W; spring plant	medium to coarse sand; dry	0.0	4	92	92.0	Mattice (1982) factorial rep = 4, n = 35
				2-5		93	97.6	
		408 paperpot; current; summer plant	medium to coarse sand; dry	0.0	4	83	78.9	
				2-5		70	79.1	
Kirkland Lake ON	1977	408 paperpot; current; spring plant	silty fine sand	0.0	4	96	123.4	
				2-5		94	119.9	
		408 paperpot; current; summer plant	silty fine sand	0.0	4	92	113.0	
				2-5		98	115.7	
Timmins ON	1980	408 paperpot O/W; spring plant	very fine sand; fresh	0.0	2	96	31.0	
				2-5		98	29.5	
		308 paperpot; current; summer plant	very fine sand; fresh	0.0	2	84	16.8	
				2-5		90	18.4	

Table 1. Continued

Location	Establishment (year)	Stock Type	Soil Texture Drainage	Burial (cm)	Growth (years)	Survival (%)	Height (cm)	Source and Experimental Design
Gogama ON	1986	2+0B/R	gravelly fine sandy loam	0.0 2.5 5.0 shallow root exposed	6	86	151.6	Paterson (1994) r.c.b. rep = 4 n = 25
						84	148.4	
						89	155.2	
						84	149.6	
Abitibi, QC Chaste Tp	1984	3+0 B/R	clay; well to moderately well drained	0.0 2.0 4.0 6.0 8.0	6	74	184.1	L'Allier (1992) r.c.b. rep = 8 n = 10
						76	179.9	
						85	177.1	
						79	168.9	
Chaste Tp	1985	2+0 B/R	clay; well drained	0.0 2.0 4.0 6.0 8.0	6	78	179.3	
						-	190.7	
						75	190.6	
						73	127.3	
Bacon Tp	1985	2+0 B/R	clay; moderately well drained	0.0 2.0 4.0 6.0 8.0	6	76	203.0	
						84	185.1	
						62	176.6	
						58	162.4	
Bacon Tp	1985	2+0 B/R	clay; moderately well drained	0.0 2.0 4.0 6.0 8.0	6	63	157.4	
						59	181.2	
						60	153.4	

Table 1. Continued

Location	Establishment (year)	Stock Type	Soil Texture Drainage	Burial (cm)	Growth (years)	Survival (%)	Height (cm)	Source and Experimental Design
Chaste Tp	1984	container	clay;	0.0	6	94	193.1	
			well to	2.0		96	197.1	
			moderately	4.0		94	196.7	
			well	6.0		79	172.0	
			drained	8.0		94	200.8	
Chaste Tp	1985	IPL 67 & styrobloc 8	clay;	0.0	6	93	198.3	
			well	2.0		94	192.4	
			drained	4.0		85	165.4	
				6.0		76	167.1	
				8.0		96	180.7	
Bacon Tp	1985	container	clay;	0.0	6	92	197.8	
			moderately	2.0		83	193.8	
			well	4.0		85	199.1	
			drained	6.0		95	197.6	
				8.0		93	186.0	

91 percent for container stock and 80 percent for bareroot. As well, planting depth had no significant effect on total height, annual growth or diameter of jack pine seedlings. The rate of frost heaving decreased significantly for container seedlings in treatments planted 2 cm or deeper below root collar. One-third of seedlings planted at 0 cm showed the effect of frost heaving compared to 13 percent of all other seedlings. Three percent of the bareroot seedlings exhibited signs of frost heaving. There were no frost-heaved trees at the 6 and 8 cm treatments (L'Allier 1992).

In the late 1970's, a number of experiments were set up to evaluate planting technique of paperpot seedlings during plantation establishment (Mattice 1982). These trials also included deep planting, planting loose or compacting the soil, and spring and summer planting of jack pine, black spruce and white spruce (see appropriate section for latter two species). They did not yield valid comparisons and were confounded by the presence of other variables, and are not statistically valid.

Jack pine was planted as overwintered and current stock in 408 paperpots (one in 308 pots) on sites near Sault Ste. Marie, Kirkland Lake, and Timmins, Ont. Planting depth treatments were normal (root collar close to soil surface but no paper left exposed) and deep (root collar 2 to 5 cm below the soil surface). On the Sault Ste. Marie site, a dry, medium to coarse sand with organic matter removed, spring planting yielded high survival (avg. 92 percent) and similar growth for normal and deep planting after four years. The current stock planted in the summer had similar height growth for both treatments but survival was 83 percent for normal planting and 70 percent for deep planting.

The Kirkland Lake site was a silty very fine sand to fine sand derived from till. After our years, there was very little difference in survival (avg. 95 percent) between the treatments planted in the spring. Normal-planted stock was taller than deep planted stock but only by the difference in planting depth. The deep-planted seedlings attained better survival and height growth than normal-planted seedlings with the summer planting.

The Timmins site was a deep stone-free very fine sand of outwash or lacustrine origin. For the spring planting both survival and height growth were similar in both treatments after two years. The summer-planted stock (308 paperpots) had better survival and height when planted deep.

BLACK SPRUCE

Table 2 summarizes the information found for the black spruce trials. In a trial established in Newfoundland by Corner Brook Pulp and Paper Company, 2+1 black spruce was planted at root collar, and with 20, 40, 60, and 80 percent of the stem above the root collar buried below ground level (Pittman 1991). The site was a well drained rich sandy loam till. The previous forest was a young balsam fir (*Abies balsamea* (L.) Mill.) stand that was drum-chopped and prescribe burned the year previous to planting. After the first year, survival at the 80 percent depth was significantly lower (77 percent) compared to all other treatments (avg. 97 percent). In the next five years, rates of further mortality did not differ significantly among treatments. Annual height growth was initially increased by deep planting; however, after six growing seasons differences in annual height increment between treatments were insignificant. Total height growth for the 40, 60 and 80 percent planting depths was significantly higher than height growth for the zero and 20 percent planting depths after six years.

Table 2. Summary of deep planting trials for black spruce

Location	Establishment (year)	Stock Type	Soil Texture Drainage	Burial (cm)	Growth (years)	Survival (%)	Height (cm)	Source and Experimental Design
Kapusasing ON	1953?	2+2 B/R	mineral	deep	5	76	53.6	Armstrong 1957
				normal		93	54.4	
				shallow		94	49.0	
			organic	deep	5	36	51.1	
				normal		89	51.6	
				shallow		94	51.6	
Kirkland Lake On	1977	408 paperpot; O/W; Spring plant	silty fine sand	0.0	4	86	34.1	Mattice (1982) factorial rep = 4, n = 35
				2-5		87	42.4	
		408 paperpot; current; summer plant	silty fine sand	0.0	4	92	43.1	
				2-5		94	39.9	
Cochrane ON	1980	408 paperpot; O/W; spring plant	sandy clay very moist	0.0	2	78	17.7	
				2-5		62	16.2	
		408 paperpot; current; summer plant	sandy clay very moist	0.0	2	70	19.1	
				2-5		66	18.2	
Corner Brook NF	1985	2+1 B/R	sandy loam; 4-6cm duff	0.0	6	92	95.5	Pittman (1991) r.c.b. rep = 5 n = 15
				20.0		91	96.4	
				40.0		92	106.0	
				60.0		96	105.9	
				80.0		72	99.3	

Table 2. Continued

Location	Establishment (year)	Stock Type	Soil Texture Drainage	Burial (cm)	Growth (years)	Survival (%)	Height (cm)	Source and Experimental Design
Abitibi QC Chaste Tp	1984	2+2 B/R	clay; well to moderately	0.0	6	54	128.8	L'Allier (1992) r.c.b. rep = 8 n = 10
			well	2.0		54	132.2	
			well	4.0		63	123.7	
			drained	6.0		53	128.0	
Chaste TP	1985	1.5+1.5 B/R	drained	8.0		66	130.5	
			clay; well	0.0	6	79	113.4	
			drained	2.0		88	120.1	
				4.0		65	104.8	
Bacon Tp	1985	1.5+1.5 B/R		6.0		76	118.3	
				8.0		66	112.4	
			clay; moderately	0.0	6	95	126.7	
			well	2.0		98	124.2	
Chaste Tp	1984	container	drained	4.0		99	126.9	
				6.0		89	122.4	
				8.0		86	114.6	
			clay; well to moderately	0.0	6	93	120.2	
Chaste Tp	1985	IPL 67 & styrobloc 8	well	2.0		91	133.7	
			drained	4.0		78	129.0	
				6.0		55	111.0	
				8.0		79	131.5	
Chaste Tp	1985	IPL 67 & styrobloc 8	clay; well	0.0	6	94	103.0	
			drained	2.0		94	114.4	
				4.0		96	105.7	
				6.0		100	124.3	
				8.0		90	111.5	

Table 2. Continued

Location	Establishment (year)	Stock Type	Soil Texture Drainage	Burial (cm)	Growth (years)	Survival (%)	Height (cm)	Source and Experimental Design
Bacon Tp	1985	IPL 45	clay; moderately well drained	0.0	6	88	108.8	
				2.0		90	92.2	
				4.0		85	100.9	
				6.0		85	105.7	
				8.0		88	102.8	
Sioux Lookout ON	1990	overwintered Spencer- Lemaire	silty clay; imperfect	<30'	2	96	23.7	Buse (1992) r.c.b. rep = 16, n = 10
				30-50		88	19.4	
				>50		73	17.4	

I. Depth of planting by percentage of tree above root collar buried.

In Quebec, concern about frost heaving is an important consideration with artificial regeneration. Trials were established in the Abitibi region in 1984 and 1985 at three different sites (Bacon 85, Chaste 84 and Chaste 85) to test the effect of planting depth on survival, growth, and frost heaving (Ancil and Cossette 1989). (Sites, design and establishment of the black spruce and jack pine trials were identical.) Black spruce in IPL 45's and as 1.5 + 1.5 (2 sites) and 2+2 (1 site) bareroot was planted with the root collar at 0, 2, 4, 6, and 8 cm below the mineral soil. Mortality of black spruce bareroot stock planted at 0 and 2 cm depths was lower (nine percent) than mortality at the 4, 6 and 8 cm depths (18 percent). Analysis of survival data using chi-square indicated a significant but weak association between survival and planting depth (L'Allier 1992). After six years, planting depth had no significant effect on total height, annual height increment or diameter. Similar to the jack pine trial, the black spruce containers exhibited significant frost heaving on seedlings planted at 0 and 2 cm (19 percent) compared to those planted deeper (eight percent). Frost heaving of bareroot stock was ten percent and not affected by depth of planting. There was no relationship between mortality and frost heaving.

A trial was established on the Lac-Seul Forest Management Unit north of Sioux Lookout, Ont. in June, 1990 with overwintered black spruce in Spencer-Lemaire roottrainers (Buse 1992). Planting depth was established at <30, 30-50, >50 percent of the tree buried. The site was a moist silty clay with imperfect drainage. After full tree harvest in 1989, the site was scarified with a Bracke in May, 1990. Survival decreased significantly from 96 percent, to 88 percent, to 73 percent for normal to deep planted treatments respectively. Prior to

planting, there were no significant differences in height of the seedlings. At the end of the second season, total height and diameter were greatest for the normal planted seedlings. The deep planted seedlings had two-year height increment growth greater than the shallow-planted seedlings. After two years, deep planting did not appear to affect growth but it had reduced survival on this moist site.

Mattice (1982) compared the performance of black spruce FH408 paperpot seedlings planted normally (root collar close to soil surface but paper covered) with those planted deep (root collar 2 to 5 cm below the soil surface) on two sites. These trials, like the jack pine trials, did not yield valid comparisons and were confounded by the presence of other variables, and are not statistically valid. The first site near Kirkland Lake was a deep ablation till with 4 to 9 cm of organic matter over silty very fine to fine sand. After four years, deep planted overwintered black spruce was taller than normal planted stock (42 cm versus 34 cm). The normal planted current stock established in July was taller than the deep planted stock (43 cm versus 40 cm). Deep planting did not have an effect on survival. The Cochrane site was a very moist lacustrine plain with sandy clay soil overlain by 20 cm of organic soil. Deep planting resulted in lower survival and height growth of spring and summer planted stock after two years.

Armstrong (1957) reported on a test of several planting methods near Kapuskasing, Ont. Seedlings (2+2) were planted in mineral and organic soils at deep, normal, and shallow depths (specific depth unknown). The stock was originally 25.4 to 30.5 cm tall and after five growing seasons averaged 49.0 to 54.4 cm in height. Survival of deep planted stock (76 percent) on mineral soil was lower than that of normal (93 percent) or shallow planted

seedlings (94 percent). On organic soils, survival (36 percent) of deep planted seedlings was very poor compared to normal- (89 percent) or shallow planted seedlings (94 percent). Variations in competition levels may have confounded the results.

WHITE SPRUCE

Mullin (1966) reported tenth-year survival and height results on 2+2 white spruce on various sites in southern Ontario (Table 3). The five treatments were root collar at -5, -2.5, zero, +2.5, and +5 cm with respect to the ground line. At the only site with an experimental design, planting depth had no significant effect on survival although Mullin recommended that planting 5 cm deep or shallow should be avoided especially on dry sites. There was an interaction between planting depth and planting method. The wedge method resulted in better height growth for shallow planting and the slit method resulted in better height growth for deep planting.

On a rich, silt loam in New York, Sutton (1967) planted 3+0 white and Norway spruce (*Picea abies* (L.) Karst.) to the same depth as in the nursery, and 5 and 10 cm deeper. After two years, planting depth had no effect on survival (avg. 89 percent). Deep planting significantly increased first-year height increment of white spruce and second-year increment of Norway spruce. In neither species, did two years of greater height increment make up for the height lost due to deep planting.

The white spruce planting technique trials were established near Sault Ste. Marie and Cochrane, Ont. (Mattice 1982). White spruce was planted as overwintered and current stock in 408 paperpots with two treatments; at normal depths (root collar close to soil surface but paper covered) and deep

(root collar 2 to 5 cm below the soil surface). The Sault Ste. Marie site was a dry site stripped of organic matter with a medium to coarse sand, not appropriate for white spruce. Survival and height of overwintered stock (308 paperpots) was greater for deep planted treatments after five years. Current stock planted in the summer had poor survival (avg. 40 percent) for both treatments but deep planted stock had greater height growth. The site near Cochrane was lacustrine in origin with clay soils and a fresh moisture regime - more appropriate for white spruce. Four centimetres of organic matter covered the mineral soil. The spring planted seedlings that were planted at normal depth achieved substantially higher survival than deep planted seedlings (92 percent versus 78 percent). Summer planted current seedlings had lower survival but with similar trends (84 percent versus 76 percent) as above. Tree height was similar for both planting dates after two years of growth.

WHITE PINE, RED PINE

A study by Carvell and Kulow (1964) indicated 2+0 eastern white pine (*Pinus strobus* L.) seedlings were sensitive to variation in depth of planting. White pine was planted with the root collar at the surface, 7.5 cm, and 15 cm below the soil surface (1/2 the foliage), and 5 cm above the soil surface on "heavy soils" in an abandoned pasture in West Virginia. After five years, only the 15 cm planting depth had significantly lower survival and height growth.

A series of trials was set out at various sites in southern Ontario (Mullin *et al.* 1954). The five treatments were root collar at -5, -2.5, 0, +2.5, and +5 cm with respect to the ground surface. White pine showed no significant differences in survival after one year although survival was lower with shallow planting. Re-evaluating the trials ten years after planting,

Table 3. Summary of deep planting trials for white spruce

Location	Establishment (year)	Stock Type	Soil Texture Drainage	Burial (cm)	Growth (years)	Survival (%)	Height (cm)	Source and Experimental Design
Kemptville ¹ ON	1950	2+2 B/R	sandy loam old field	-5.0 ²	10	85	106.7	Mullin (1986) r.c.b. rep = 3 n = 50
				-2.5		76	91.4	
				0.0		78	103.6	
				2.5		72	85.3	
				5.0		77	91.4	
Ithaca NY	1963	3+0 B/R	silty loam; well drained	0.0	2	89		Sutton (1967) split - split plot rep = 4, n = 20
				5.0				
				10.0				
Sault Ste. Marie ON	1977	308 paperpot O/W; spring plant	medium to coarse sand; dry	0.0	4	75	27.9	Mattice (1982) factorial rep = 4, n = 35
				2-5		80	31.7	
Cochrane ON	1980	408 paperpot; current; summer plant	medium to coarse sand; dry	0.0	4	38	180.0	
				2-5		43	194.0	
		408 paperpot O/W; spring plant	clay; fresh	0.0	2	92	10.8	
				2-5		78	10.6	
		408 paperpot; current; summer plant	clay; fresh	0.0	2	85	12.2	
				2-5		76	12.4	

1. Data from Experiment C only

2. Negative value refers to shallow planted, positive numbers are deep planted

Mullin (1967) concluded that exact regulation of planting depth is of little importance to survival and growth. White pine appeared more tolerant of variation in planting depth than red pine (*Pinus resinosa* Ait.) or white spruce. Second-year results from the red pine study indicated that mortality increased significantly with progression from deep to shallow planting. Results of measurements after ten years (Mullin 1964), showed the same survival trends. However, planting depth had a significant effect on height after ten years; trees planted at 2.5 cm above root collar were tallest (4.0 in) and trees planted at five cm below root collar were shortest (3.6 in.) This improvement in growth was considered less important than the improved survival. Mullin (1964) suggested that deep-planted trees had faster access to moisture whereas shallow planted trees had better access to the fertile surface layer.

SOUTHERN PINES

There are a number of reports on trials that were established in the United States southeast in the 1950's and 60's using southern pines. Deep plantings of southern pine have produced mixed results depending on site, annual weather conditions and stock size. These results may provide some indication of how jack pine may be affected by deep planting.

Current height growth of 1+0 loblolly pine (*Pinus taeda* L.), grown on well drained upland clay soils in North Carolina was stimulated by deep planting and growth differences continued to be significant for a period of two years after planting (Slocum and Maki 1956). Survival was not affected significantly by amount of stem buried but greater mortality and less height growth was apparent for shallow-planted trees. Results of pond (*Pinus serotina* Michx.), Virginia (*Pinus virginiana* Mill.) and shortleaf pine (*Pinus*

echinata Mill.) plantings indicated a similar response to deep planting. But on poorly drained clay and silt soils in Mississippi, deep planting loblolly pine resulted in poor survival and reduced height growth (Switzer 1960). He recommended that on these sites, seedlings should be planted at, or only slightly below, the original ground line. As a result of trials in Virginia with loblolly pine, Dierauf (1984) arrived at the same conclusions.

Following trials with longleaf pine (*Pinus palustris* Mill.) seedlings on wet and dry sites in Mississippi, Smith (1954) recommended that machine planters of longleaf pine seedlings strive to plant them with the root collars at ground level or 1.3 cm below ground level. Results after 22 years supported the same conclusions (Smith 1976). Shallow planting was not recommended.

Various grades of small stock slash pine (*Pinus elliottii* Engelm.) were planted at root collar, 1/2 stem buried, and to the terminal bud in sandy, sandy loam, and loamy sand soils in South Carolina (McGee and Hatcher 1963). After five years, survival of all grades of stock on all soils was increased significantly by deep planting. The best five-year height growth was obtained by planting halfway between root collar and the bud. The benefits of this planting procedure seemed to increase with a decrease in quality of planting stock.

This is in contrast to a trial using small stock 1+0 loblolly and slash pine planted in a fine sandy loam in Texas (Koski 1960). The treatments were planted at root collar, 1/2 stem buried and to the base of the terminal bud. After one year, survival was poor overall but worse for deep planted seedlings and growth increment was better on the larger stock and on deep planted stock. Koshi suggested deep planting may have a slightly adverse effect in rainy years and in drier seasons could have improved survival. In a

study with slash pine over a range of sites in Alabama and Mississippi, Swearingen (1963) found seedling growth was increased by deep planting and deep planting up to the terminal bud had no adverse effect on survival.

WESTERN SPECIES

In Washington, 2+0 ponderosa pine (*Pinus ponderosa* Laws.) was planted at normal depth, cotyledons at ground line, and lowest needles at ground line (Dick 1964). After one year, survival of the deep planted stock was significantly higher than stock planted at other depths. This greater survival may have resulted from placement of the roots in soil with more moisture. On very dry sites in Arizona, 2+1 ponderosa pine was planted at normal depth and up to the terminal bud

(Heidmann 1963). Differences in survival (-60 percent overall) were not significant and over half of the mortality was caused by drought.

A study of deep planting Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco Var. *menziesii*) was initiated by Strothmann (1971) on a gravelly loam, dry ridge slope in northern California. Seedlings (2+0) 20 to 25 cm tall, were planted with root collar at ground level, and with 25 and 50 percent of the stem buried. Survival was greater than 93 percent with no significant differences among treatments. Total height after three years was the same for all treatments although each had different heights after planting. After ten years, survival remained unaffected by planting treatment, and there were no differences in height (Strothmann 1976).

3. FACTORS AFFECTING GROWTH AS RELATED TO DEEP PLANTING

The growth and survival of seedlings depends on many environmental and physiological factors whether they are planted shallow, normal, or deep. The factors identified that have some effect on deep planting include a) moisture relations, b) nutrient relations, c) root deformation, d) rooting habit, e) heat stress, f) frost heaving, and g) low soil temperature. Most of these factors are interrelated and a change in one or more external environmental factors causes a chain reaction.

MOISTURE RELATIONS

Soil moisture probably has more effect on initial seedling survival than any other factor. Many authors (Slocum and Maki 1956; McGee and Hatcher 1963; Cleary *et al.* 1978; Lantz *et al.* 1988) attribute increased survival and height growth to a greater availability of moisture with depth on a range of dry to well drained soils. Many authors note that shallow planting is dangerous and most recommend avoidance of planting with the root collar above the soil surface (Mullin 1964, 1966; Smith 1976; Cleary *et al.* 1978). Deep planting may have an adverse effect in rainy years but in a dry season could improve survival (Koshi 1960).

Although soil temperatures and fertility will usually decrease with depth, deep planting is frequently advantageous to survival and growth (Sutton 1967), presumably because of improved moisture relations and improved anchorage. According to Sutton (1978), the amount of soil moisture

available to an outplant with a root system of given dimensions will also depend on the depth at which that root system is set into the soil. A greater volume of soil will occur within a given distance of the roots of a deeply planted tree than those planted less deeply, and it will remain moister for longer.

Very little is mentioned in the literature about planting deep in organic or wet soils. It was not recommended by some authors (Switzer 1960; Sutton 1969). The only documented report (Armstrong 1957) of deep planting in organic soils resulted in 36 percent survival compared to 89 percent with normal planted seedlings. Sutton (*pers. comm.*, 1991)⁴ suggested that planting black spruce with the root collar 1 to 2 cm lower in poorly drained soils, if needed to stabilize the outplant, may be beneficial; with stability, good stock will readily develop a new root system.

NUTRIENT RELATIONS

Root growth and development are influenced by soil fertility at every stage from germination onwards (Sutton 1969). The uptake of mineral nutrients depends on movement through the soil to the root surface, the amount of root surface in contact with the soil, the absorption capacity of the roots and the rate at which minerals are being used by the plant (Kozłowski *et al.* 1991). Relatively large quantities of nutrients are found in the organic layer and the soil immediately adjacent to it. Most root growth occurs in this area in natural soils to take advantage of these

⁴ Dr. Roy Sutton, Research Scientist (retired) Canadian Forestry Service, Sault Ste Marie, Ont.

nutrients. In deep planted spruce, adventitious roots readily develop above the root collar when the soil contacts the stem. Coincidentally this is also the zone of the highest nutrient availability, and usually the adventitious roots develop into the major root system of the tree while the original root mass languishes in a shrivelled mass lower in the sub-soil. New jack pine roots develop from the original root mass and grow toward the area of higher nutrients.

ROOT DEFORMATION

Deep planting may affect root development. Deep planting increases the probability of L or J-rooting because planters tend to cram roots deeper into a normal depth hole instead of digging a deeper hole (Carvell and Kulow 1964; Cleary *et al.* 1978). Brissette and Barnett (1989) tested the effects of J-rooting and depth of planting on survival and growth of loblolly pine 1+0 seedlings in a greenhouse bed subjected to moisture stress. Seedlings were planted at root collar, 3 cm below, and 2 cm above the soil surface respectively. Results from measurements taken over a 12-week period indicated that shallow planting regardless of root orientation can cause mortality and deep planting regardless of root orientation increased survival. The straight-planted seedlings consistently outperformed the J-rooted trees. These conclusions applied only to well drained soils. It appears that deformed roots are less efficient in both water uptake and new root and shoot growth than are straight roots.

ROOTING HABIT

The development of adventitious roots above the root collar of black and white spruces is a common phenomenon when soil moisture conditions are correct (Sutton 1969). Adventitious rooting may be regarded as a mechanism of repair for root systems unbalanced by injury or stress (Sutton 1980). In the case of deep planting, adventitious roots develop as an adjustment by the outplant to the more inhospitable soil conditions than those in which the plant was raised. The development of adventitious roots is important not only for nutritional and water relations but also for the development of stability. Reports of deep planted spruce describe the development of adventitious rooting (Sutton 1967; McClain 1981; Pittman 1991). Sutton (1967) found that within three months, more than half of white spruce deep planted in a well structured fertile silt loam had developed adventitious roots. Deep planting did not inactivate the preexisting root system and adventitious roots supplemented rather than supplanted the old root system. These results probably apply only to soils of medium or high fertility that are not poorly drained. In other circumstances a large part of the nursery root system may be inactivated by deep planting. In a study of black spruce root development comparing Ontario tubelings, plugs, and bare root stock, McClain (1981) found that regardless of stock type, black spruce characteristically developed an entirely new root system when the stem above the root collar was covered with soil or organic matter. This new root system consisted entirely of adventitious roots growing in a tier above the original root mass which was of low vitality. It was this development of a new root system that eventually met the requirement for anchorage and absorption.

Pines of the species used in reforestation in Ontario develop adventitious roots much less readily than do our spruces. According to Sutton (pers. comm., 1991)⁵, it is not characteristic for jack pine to develop adventitious roots. This is also true for loblolly pine (Slocum and Maki 1956) and slash pine (McGee and Hatcher 1963). The deeply buried roots of loblolly pine do not die, nor do new rootlets develop above the root collar on the buried stem. The main tap root continues to elongate and penetrate further into the soil while the lateral roots continue to develop horizontally although at a slightly greater depth than those of shallow-planted trees. Nothing was found in the literature that described root development in jack pine when deep planted.

However, white pine seedlings that are planted very deep develop a new superficial layer of roots above the older root system (Carvell and Kulow 1964). Also, the upper roots of the original root system developed upward into the surface soil. Comparison of root systems of deep-planted seedlings with those planted at normal depths indicated the latter had a much sturdier network of descending roots. Carvell and Kulow suggest that complications caused by very deep planting were gradually corrected by adjustments of the seedlings' root system.

HEAT STRESS

Heat is probably the most overlooked cause of death of newly transplanted bareroot trees (Stroempl 1990). Heat causes stress through direct and/or reflected sunlight to the cambium which; is most sensitive at the interface of the soil surface and the tree stem.

This interface is where the highest temperatures are most likely to occur. Temperatures above 50-60°C for brief periods can cause bark lesions, scald spots and desiccation of the cambium (Seidel 1986). Soil surface temperatures near the root collar have been measured at 68°C (Stathers and Spittlehouse 1990). Cambial damage results in reduced water flow through the stem and this can cause moisture stress in the seedling. It is possible that deep planting to the foliage will reduce temperature and damage to the stem because the foliage provides some measure of shade in this area.

FROST HEAVING

Frost heaving requires a combination of specific soil temperature, soil moisture, and soil textural conditions (Stathers and Spittlehouse 1990). It is most likely to occur in exposed, fine textured mineral soils that are subjected to repeated freezing and thawing cycles (Sutton 1969). The severity of frost heaving can vary greatly from year to year and episode to episode within a year. Deep planting of seedlings while the soil is warm enough for good root growth to anchor the seedling can minimize this problem. From experience with mounding in Sweden (Adelsköld and Örlander 1989), deep planting container stock in the mound on fine-textured mineral soil has shown to reduce the risk of frost heaving considerably. From the literature reviewed, only the trials in Quebec described serious problems with frost heaving (Ancil and Cossette 1989). On two sites, frost heaving rates were over 50 percent. Deep planting somewhat reduced frost heaving and

⁵ Dr. Roy Sutton, Research Scientist (retired) Canadian Forestry Service, Sault Ste Marie, Ont.

is recommended in clay soil for container stock in Quebec (L'Allier 1992).

LOW SOIL TEMPERATURE

Trees planted in cold, wet soil in the spring may transpire far more water than they are able to take up, particularly if the soil is also poorly aerated (Sutton 1969). New roots so not develop and old roots do not function effectively. The decrease in absorption of aerated water at low temperatures is caused largely by increased resistance to water flow through roots (Kramer 1983). Trees may then be susceptible to water stress induced by low soil temperature and poor root-soil contact

when first planted (Grossnickle 1988). A decision to expose the mineral soil with the aim of raising soil temperature should consider the side effects of the practice. If this increases the danger of frost heaving (Sutton 1989) or heat stress, then deep planting may provide one option to alleviate these stresses. No information was found to indicate whether trees that were planted 5 cm or more deep suffered as a result of the lower temperature at greater depths. While trees do not appear to suffer, Pittman (1991) suggested low temperature in the mineral soil may explain why the original roots failed to develop.

4. CURRENT PLANTING PRACTICES

In Ontario, tree plant guidelines are described in the Standard contract for contractors. In the planting specifications section it states⁶: "Each tree shall be planted to a depth so that, after filling in and compacting soil about the roots, the soil comes to a point at or near the root collar on the tree stem where roots are not exposed and no branches and tree leaves are covered with soil. In the case of container stock each container shall be planted so as not to leave any of the paperpot (and/or plug) showing above the ground." These guidelines apply across Ontario, especially for jack pine. There appears to be a certain amount of leeway with black spruce. If trees are planted with the root collar buried up to the foliage, deep planting is not considered a serious problem and penalties are not applied. On the other hand, planting that leaves exposed plug or roots is penalized.

Those companies with Forest Management Agreements can determine their own practice and most follow the guidelines as described in the tree planting contract. In Thunder Bay, Ont. typical practice for Abitibi-Price since 1985 has been to plant black spruce (bareroot or container seedlings) up to, or 2 cm deeper than, the first live branches (P. Poschmann Feb. 1993 pers. comm.)⁷. Poschmann stated that (in one example) seedlings 30 to 36 cm high with a caliper of

1.8 mm were planted with the root collar 7 to 8 cm into the mineral soil. Typical soils in the area are loams and silt loams.

In the Longlac, Ont. area, deep planting of black and white spruce is standard practice at Kimberly-Clark Forest Products (K. Lennon Feb 1993 pers. comm.)⁸. On low-lying organic soils and sphagnum hummocks, black spruce bareroot stock is planted with the root collar as much as 5 cm below the surface. Burial of some foliage is acceptable so as to ensure", that planters do not leave roots exposed, to provide stability to the outplants, and to ensure that if the area is dry the roots will have enough moisture. White spruce 2 + 2 stock is planted up to 5 cm deep on clay loam and clay soils.

The silviculture contract of the British Columbia Ministry of Forests reads "the seedling shall be planted to a depth such that after filling and tamping the root collar must be at or below the surface of the acceptable planting medium with no branches or needles buried. Containerized seedlings shall have the top of the 'plug' below the soil surface"⁹. According to von Hahn (pers. comm. 1991)¹⁰, the B.C. Forest Service allows planting 1 cm, more or less, below the root collar. Lodgepole pine is planted with the root collar 'two fingers deep' and spruce is planted 'deep' on mounded sites.

⁶ from the Ontario tree planting contract Schedule B - Planting Specifications Paragraph 4.4

⁷ Paul Poschmann, Management Forester, Abitibi-Price Inc., Thunder Bay, Ont.

⁸ Ken Lennon, Supervisor Forest Renewal and Maintenance, Kimberly-Clark Forest Products Ltd. Longlac, Ont.

⁹ Silviculture Contract, B.C. Min. of For. Schedule A Paragraph 2.2.2 11

¹⁰ Charles von Hahn, Planting Program Specialist. B.C. Min. of For. Victoria, B.C.

Mead Corporation in Escanaba, Michigan normally plants all container stock with 'two fingers' above the top of the plug or to the bottom of the foliage. (Becker, pers. comm. 1991)¹¹. This has been their practice with all species since the early 1980's. They plant three million trees annually, of which 10 to 20 percent are jack pine.

Paterson (pers. comm. 1991)¹² normally plants all his experimental stock 2 to 3 cm below the root collar and up to 5 cm deep on dry sites.

In the Abitibi region of Quebec¹³, seedlings must be planted such that the root collar is placed between 2 to 5 cm into the humus where the humus is a minimum 5 cm. No foliage can be covered by organic material. Otherwise seedlings must be put in the mineral soil at root collar depth.

In Sweden, recommendations are made for planting in mounds (Adelsköld and Örlander 1989). Six different microsite locations were defined following mounding site preparation. As well, ten different site classes were distinguished with respect to soil moisture class, soil texture, and risk of drought after planting. The seedling is planted deeper than normal in spots on inverted humus, the mound on inverted humus,

themound on undisturbed humus and, for sites with fine textured soils, on the mound on mineral soil. Seedlings are never planted deep in the patch.

Mound planting is not a concern in Ontario because mounding is not generally practiced. On the basis of site preparation trials comparing the Bracke patch scarifier and Bracke moulder and outplanting of bareroot jack pine and black spruce, there is no benefit from mounding site preparation on the sites tested (Sutton 1991).

According to Gordon (pers. comm. March 1991)¹⁴, white spruce must be planted at the root collar on fine textured soils. It is his opinion that deep planting will result in the seedling going into check. He postulates that seedlings planted at root collar in mineral soil surrounded by dry duff will not go into check. Gordon also suggested that if deep planted on coarse-texture soils, seedlings will survive but not grow well on such sites.

Personal experience has shown that it is difficult to plant white spruce very deep (more than 4 cm above the root collar) because the stock is generally of a larger size than black spruce or jack pine and requires a larger plant hole or slit.

¹¹ Chuck Becker, Research and Planting Operations Forester, Mead Corp. Escanaba, MI.

¹² John Paterson, Regeneration Specialist, Ontario Forest Research Institute Ministry of Natural Resources, Sault Ste. Marie Ont..

¹³ From the planting contract of Ministère des Forêts, Que.

¹⁴ A.G. Gordon Research Scientist, Ontario Forest Research Institute, Ministry of Natural Resources, Sault Ste. Marie, Ont.

5. SUMMARY AND CONCLUSIONS

Some general conclusions may be drawn from this review. Factors such as moisture, nutrient relations, rooting habit, and soil temperatures affect the deep planted seedling. Site specificity is just as important for deep planting as it is for species selection. Shallow planting is not recommended. Any planting operation is dependent on weather conditions. Many of the trials established to test planting depth have not been in the ground long enough to draw firm conclusions about survival and growth.

JACK PINE

The results from the trials indicate that deep planting up to 4 cm above the root collar will not be detrimental on typical jack pine sites, and may even promote survival and growth of seedlings.

Three references to deep planting jack pine were found in the literature. In the trial near Gogama, Ontario, deep-planted jack pine, both bareroot and container stock, performed well on an appropriate jack pine site. Survival was not affected by deep planting. Any height disadvantage that resulted from deep planting was overcome after four years and deep-planted container stock was taller than other treatments.

The Quebec trials (bareroot and container) were all planted in clay soils. No clear advantage in survival or height was gained by normal versus deep planting. Preliminary recommendations for planting jack pine container stock to minimize frost heaving and maintain growth should be to set outplants a minimum of four cm below the

root collar on clay soils and microsites comparable to those of the trial (i.e. side of the mound). For bareroot stock, planting depth should not exceed two cm below root collar to minimize mortality without affecting rate of frost heaving and tree growth (L'Allier 1992). These standards are applicable only in the Clay Belt in northwestern Quebec.

Of the six experiments described by Mattice (1982), only one deep-planted treatment (summer planted) had poor survival compared with the normal-planted treatment. Total height growth on four sites was better for deep-planted stock, and on the other two sites height growth was less only by the difference in planting depth. All trials involved container stock.

No mention was made of how jack pine roots react in the soil. No indication was given to indicate if foliage was buried (it was in some cases) or how it reacted to burying. It is known that adventitious roots seldom if ever develop from a buried stem. It would appear that jack pine can thrive if planted up to five cm deep on a typical (dry) jack pine site and that the benefit is a result of improved moisture conditions. Paterson (pers. comm., 1991) suggested that any jack pine planted deep on dry sites will benefit from enhanced moisture conditions. Nevertheless, most jack pine is planted at root collar level with the mineral soil with some leeway of 1 or 2 cm to deep planting.

BLACK SPRUCE

Black spruce can be planted at least to the level of the first branches in mineral soils, without affecting performance. There maybe some concerns with survival if the seedlings are planted deeper than this (foliage buried) in imperfectly drained or wetter mineral soils. In soils susceptible to frost heaving deep planting (- 4 cm) may increase survival In sphagnum, planting 2 to 4 cm deep will provide more stability to the seedling which may more than offset the disadvantages of deep planting in a poorly drained soil Adventitious roots will grow and form the main elements of the root system.

Five different trials on 11 different sites were reported for black spruce. The Quebec trials (bareroot and container) are the most extensive. Survival was reduced by deep planting (6 to 8 cm) in these trials but height growth did not seem to be adversely affected. Preliminary recommendations for black spruce planting are the same as those of jack pine, a minimum of 4 cm for container stock and no more than 2 cm for bareroot stock (L'Allier 1992). The results of planting technique trials in Ontario were site specific; one site had reduced survival with deep planting and the other had better survival. In the Sioux Lookout, Ont. trial, deep planting did not appear to be affecting growth but it had reduced survival (especially when >50 percent of seedling is buried) on the moist site. The Kapuskasing trial found that deep planting (depth unknown) was detrimental especially on organic soils. Most planting operations are not too concerned about planting up to 2 cm deep, but Abitibi-Price in Thunder Bay and

Kimberly-Clark in Longlac have standards that allow deep planting up to 2 cm past the first live branches in mineral soils, and up to five cm above the root collar in organic soils. For conditions specific to Western

Newfoundland, planting such that 40 percent of the stem is buried is likely to promote early height growth while maintaining a high rate of survival.

It is recognized that deep-planted stock will produce adventitious roots which will evolve into the main root mass of the tree. Deep planting allows the tree to take advantage of higher moisture levels deeper in the soil. Most expert sources (Sutton, Paterson, Fayle¹⁵, Krause¹⁶) recommended deep planting of black spruce with the root collar 2 to 3 cm deep, on mineral soil when the drainage is good. For sturdy transplant stock, Sutton recommended planting one to 2 cm deeper on poorly drained sites to provide anchorage for the root system. When planting in organic soils there is often no clear definition of soil surface and placing trees at root collar can provide a wide variation.

WHITE SPRUCE

There is not enough information available for conditions in northern Ontario to determine if deep planting has a detrimental effect on performance of white spruce. Adventitious roots will develop but with unknown effects on establishment and growth. The recommendation at this time is to plant white spruce at root collar level to mineral soil.

Only three references were found which referred to deep planting of white spruce. Of

¹⁵ Helmut Krause, Faculty of Forestry University of New Brunswick, Fredericton, NB.

¹⁶ David Fayle, Faculty of Forestry, University of Toronto, Toronto, Ont.

the trials established in northern Ontario only one was on a "good" white spruce site. Survival of deep-planted stock was poorer than that of normal-planted stock. On the dry sand site, survival was better for the deep planted stock possibly because of better moisture conditions. Height growth was similar or better for deep-planted stock. In the

New York and southern Ontario, trials planting depth had no effect on survival. Mullin (1966) stated that planting deeper than five cm below the root collar should be avoided especially on dry sites. This conflicts with evidence that says planting deep on dry sites would be beneficial because of better moisture relations.

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